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| Type of documents: | <input type="checkbox"/> Glossary | <input type="checkbox"/> Cx process | <input type="checkbox"/> Project | <input checked="" type="checkbox"/> Tool | <input type="checkbox"/> Model |
| Type of building: | <input checked="" type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 | <input type="checkbox"/> 5 |
| Type of commissioning: | <input checked="" type="checkbox"/> Initial-cx | <input checked="" type="checkbox"/> re-cx | <input checked="" type="checkbox"/> retro-cx | <input type="checkbox"/> Continuous-cx | |
| Glossary check: | <input type="checkbox"/> yes | <input checked="" type="checkbox"/> no | | | |
| MQC task: | <input type="checkbox"/> Program | <input type="checkbox"/> Design | <input type="checkbox"/> Elaboration | <input checked="" type="checkbox"/> Realization | <input checked="" type="checkbox"/> Operation |

A DEVELOPMENT OF CX TOOLS FOR HVAC SYSTEM IN RESIDENCE

A MEASUREMENT METHOD OF ACTUAL THERMAL PERFORMANCE OF DETACHED HOUSES

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1. Introduction

This paper describes the measuring method of actual thermal performance of residential detached houses.

The ratio of heating and cooling energy used in all residential houses in total energy consumption in Japan is about 7%. This number and its significance have not changed so much in the last decade.

The effect of the thermal performance of the envelope surface, such as walls, roofs and windows, on the energy used by HVAC system is not so large in normal office buildings. In the detached houses, however, it is not too small to be neglected because of the relatively largeness of the wall surface to the volume of the room space. If the house does not have the proper thermal performance, it is very difficult to determine which the main reason is, the malfunction of the heating equipment or bad thermal performance of the envelope? Both of them may cause a big waste of energy. Thus, it is very important to estimate the actual thermal performance of the houses when we do commissioning of HVAC system in order to save energy and reduce the environmental impact.

ASHRAE and JIS have test standards for some of facilities, such as filter dirt and AC evaporator efficiency. Unfortunately, it should be said that the measuring method for the actual thermal performance of houses has not been established yet. A group led by Dr. Matsuo and Dr. Sakamoto has been studying on the testing method which is based on the transient heat transfer process of the wall since 1970. Recently they have reported the results of measuring error of their method. In the near future, their method will be standard testing method in Japan if people don't have time of more than 3 days for the measurement and have many measurement tools.

The other hand, SP (Swedish National Testing and Research Institute) have developed the testing method for prefabricated house which is based on the steady state heat transfer process of the walls. (In this paper, we call this SP-Method) It is obviously that the applicability of this method depends on the heat lightness of the wall relative to the variation rapidness of the outdoor weather condition. We thought that recently Japanese house is so light that we can apply the SP-Method.

It is obvious that easiness and quickness are required of the measurement method. The reproduction of the result is also required. The reproduction means same results of the thermal properties of the envelope among different conditions.

Addition to these, smallness of the measurement equipment is also required. Theoretically, there will be some relation between the measurement term and reproduction. The shorter the measurement term is, the worse the reproduction is. We can not make clear the relation without a multitude of actual trials.

In these points of view, we tried the measurement method in some houses and analyze the reproduction of measurement results. In this paper, we describe the measurement method and report the measurement results of detached houses in Kawasaki, Tsu and Kobe.

2. The Measurement Method

Our measurement method is basically similar to the SP-Method. The walls of our houses are consists of woods and thin gypsum boards. Therefore the weight of our houses is relatively light. So the influence of the heat capacity of the wall can be neglected. We assume the temperature variation can be based on the steady state heat transfer process. The accuracy of the estimated value measured by our method depends on the wall weight and the variation speed of the weather conditions. If the temperature rapidly changes during the measurement, the influence of the heat capacity becomes large.

The measurement term is one week. The measured data in the daytime are not used for the estimation of the thermal property because the solar heat effects on the room temperature in the daytime. In the measurement term, it is better that there is no resident in the house. People give room some heat from the body. It can be measured easily. Residents can not use gas appliances and hot water in the measurement term.

The equipment needed in the measurement method is as follows.

1. The electric heaters
 - a) The number of heaters is same as that of the rooms in the measured house.
 - b) The output is 500 – 1000W. It costs about 50 dollars in Japan.
 - c) There are three types of electric heater, such as the forced air convection type, natural convection type with low surface temperature and wide surface area and the radiation type by halogen light with high temperature. The last type is not suitable for this measurement because it warms up the wall surface directly and makes great temperature distribution.
2. Temperature recorder
 - a) The number of temperature recorder is same as that of the rooms in the measured house.
 - b) The measurement interval is 1 min and the maximum number of recording datum is 10,000. It costs about 200 dollars.
3. Stand like a tripod to hanging the temperature recorder
 - a) The number of stand is same as that of the rooms in the measured house.
 - b) The height of the stand is about 1.5m from the floor to hang temperature recorder at 1.2m height.

The specifications of the measurement method are as follows.

1. Hang the temperature recorder at 1.2m height at the center of the each room.
2. Put the electronic heater in each room in the measured house.
 - a) When you put the heater in the room, you must take care of the direction of the heater not to face the

temperature recorder directly. It would monitor higher than real temperature of the room space.

3. Set the measurement interval of the temperature recorder 1min.
4. Check the whole electricity in the house by the electric meter set by the electric supplier.
5. Switch the heaters on.
6. Start temperature recording.
7. Monitor for a week.
8. Check the whole electricity every day.

The specifications of the estimation of the thermal performance are as follows.

1. Calculate the space average \overline{Tin}_m of recorded temperature $Tin_{j,m}$ (j denote the room number and m denote the record number) in the house each 1 minute.

$$\overline{Tin}_m = \sum_j A_j Tin_{j,m} / \sum_j A_j$$

Here, A_j is the floor area which Tin_j represents.

2. Calculate the temperature difference ΔT_m between the averaged indoor temperature and the outdoors Tot_m .

$$\Delta T_m = \overline{Tin}_m - Tot_m$$

3. Average the temperature difference every 1 hour $\overline{\Delta T}_n$ and get the standard deviation δ_n .

$$\overline{\Delta T}_n = \sum_{m=m0+1}^{m0+60} \Delta T_m / 60$$

$$\delta_n = \frac{1}{60} \sqrt{\sum_{m=m0+1}^{m0+60} (\Delta T_m - \overline{\Delta T}_n)^2}$$

4. Calculate the electricity W in 1 hour.
5. Select representative ΔT from $\overline{\Delta T}_n$.

We choose ΔT of the smallest δ_n during 0:00 to 3:00 at night.

6. Get the thermal performance value of the house HLC by $W / \Delta T$

Velocity of outdoor wind and sky radiation should be measured to get more precise result. Theoretically, wind velocity varies only heat transfer resistance of the outside surface, which is less than 2% of the total heat resistance of the insulated walls. Sky radiation has effects on the average temperature difference among the outdoors and the rooms. In our trials, their effects are too small to be described by measuring error.

3. Examples of measurements

3-1. TEPCO-Labo house

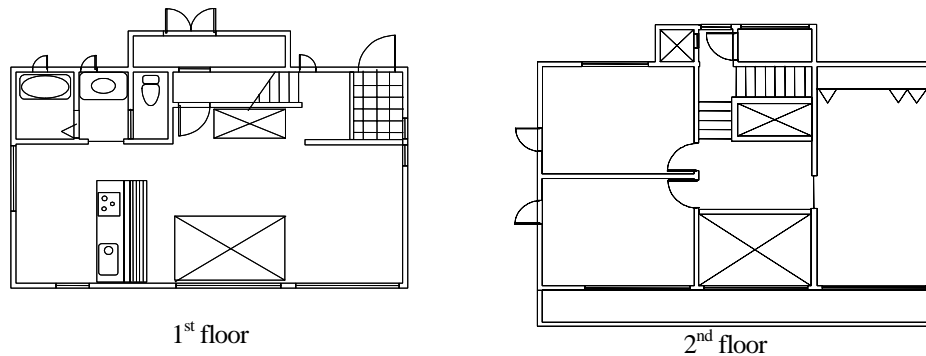


Figure-1: The plan of the TEPCO-Labo house in Kawasaki

Table-1: Theoretically calculated thermal performance of the testing house

| | | |
|------------------|--|-----------|
| By ventilation | $0.5 \text{ times/h} * 0.35 \text{ W/m}^3\text{K} * 270\text{m}^3 =$ | 40.5 W/K |
| Through Wall | | 34.8 W/K |
| Through Openings | | 100.0 W/K |
| Through Roof | | 12.5 W/K |
| Total | $40.5+34.8+100.0+12.5=$ | 187.8 W/K |

Figure-1 shows the plan which is build in the backyard of TEPCO Laboratory in Kawasaki (near Tokyo). The floor of the house is specially insulated on both side of the concrete slab for the other particular measurement. We calculate the heat flux through the concrete slab by product of temperature difference between two surfaces of the concrete slab and the thermal properties of the concrete slab. Then we substitute the heat flux from the measured electricity. The remains are the heat loss of the testing house excepting the heat flux through the ground. Table-1 shows the theoretically calculated thermal performance of the testing house. This is in the extremely highly insulated level in Japan.

Figure-2 shows the relation between temperature difference and modified electricity. Modified electricity means the ground heat loss subtracted from the electricity. The estimated HLC is 165, which is 80% of the theoretically calculated value. The correlation coefficient is over 0.9 which means that this result has a good reappearance.

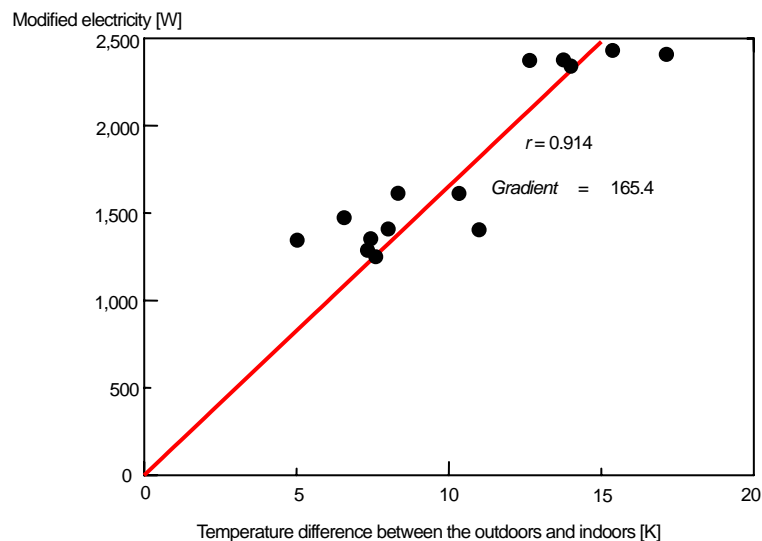


Figure-2 The relation between temperature difference and modified electricity

Temperature difference is result of subtraction the outdoor air temperature from the average of indoor room temperature.

3.2 Demo house in Tsu

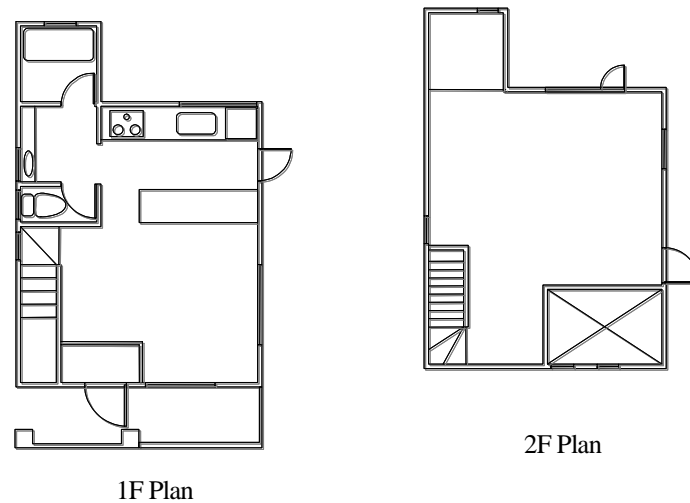


Figure-3: The Plan of Demo house in Tsu

Total Floor area 73m^2 , theoretically calculated thermal performance of the house = 152 W/K

We measured the demo house built in Tsu (middle of Tokyo and Osaka) which plan is shown in Figure-3. The house has crawl space which is ventilated to the outdoor air and the floor is insulated on the crawl side. Thus the crawl space is regarded as the outdoors and the floor is an insulated envelope. This is normal insulation way in warm region in Japan.

Figure-4 shows the relation between the temperature difference and the electricity recorded in 10 days started from October 10th 2003. The correlation coefficient is 0.96. It means the accuracy of the measured result.

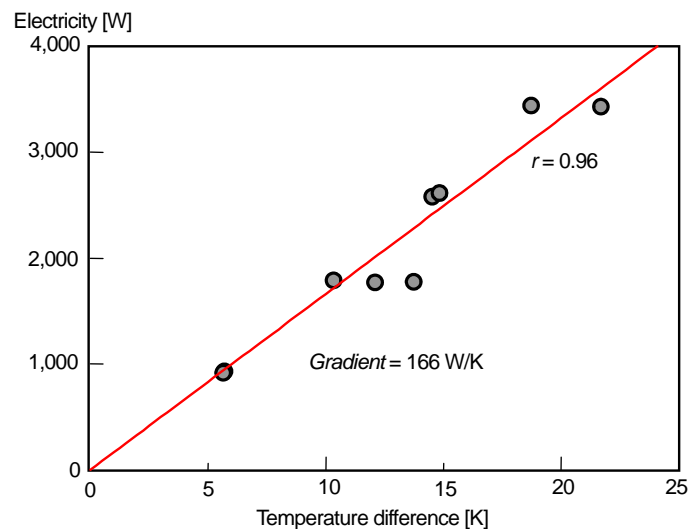


Figure-4: Recorded temperature difference and electricity

Addition to this measurement, we measured the house again in January 2004. The winter result is 171W/K , 3% larger than the autumn result. But when we take heat loss caused by natural ventilation from each result, the remains are almost same, 150.2 (autumn) and 149.5 (winter). Thus, it is can be said that the thermal performance of envelope is accurate at measurement.

3.3 YKKAP-Labo House

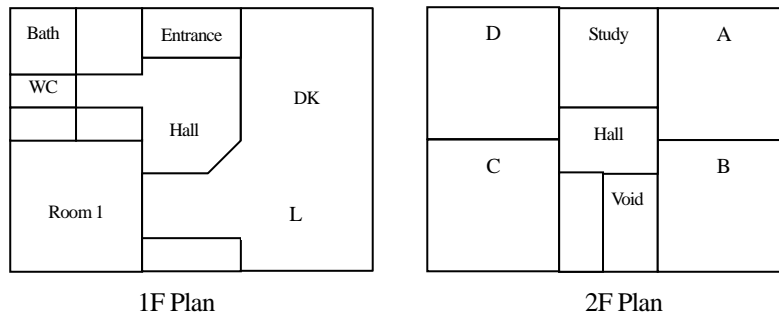


Figure-5: The plan of YKKAP-Labo house in Kobe

Total Floor area 146m^2 , theoretically calculated thermal performance of the house = 391 W/K

Figure-5 shows the plan which is build in the yard of YKK-AP Laboratory in Kobe (near Osaka). Unfortunately, we could measure only three days. The results are shown in Figure-6. Temperature difference changes in the range of 2 K. This shows the influence of the heat capacity of the house. Neglecting this variation, the estimated HLC equals 352 W/K , 90% of the theoretical value.

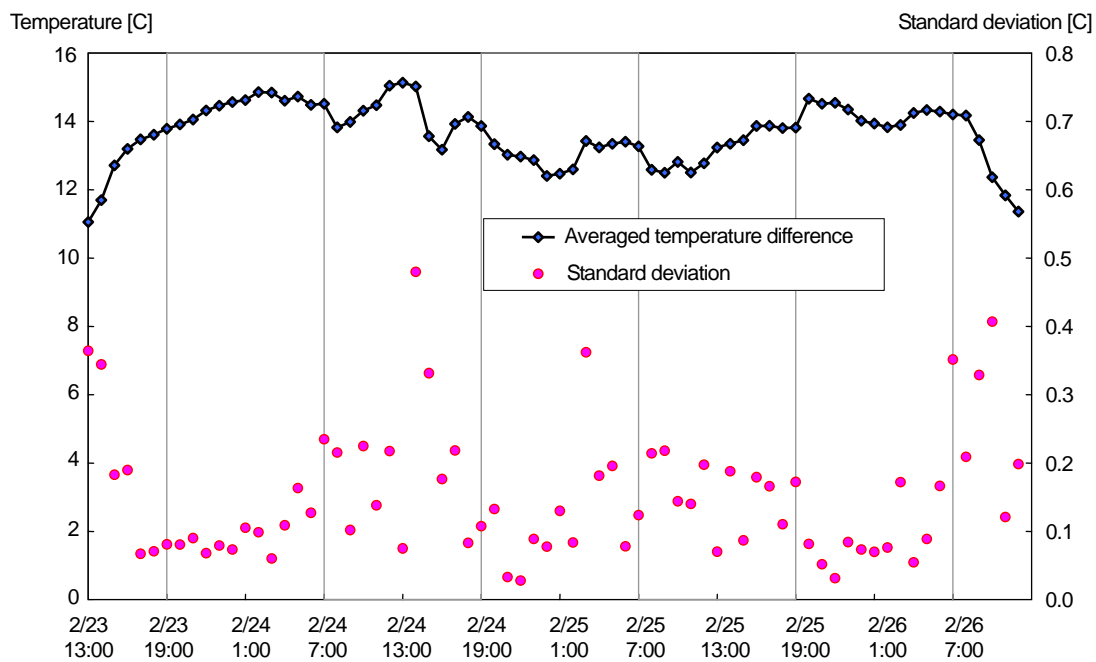


Figure-6: Measurement result of temperature difference and standard deviation

4. Influence of heat capacity of the walls

We calculate temperature variation of house theoretically. It is based on 1-dimensional transient heat transfer process. There is no temperature distribution in house and the walls are consisted of exterior wall, window, roof and floor. Heat loss by ventilation 0.5 times per hour is also considered. The walls are divided by 1mm thickness in order to

calculate the influence of heat capacity accurately. The outdoor temperature is 0 constantly. The initial temperature of all points is 0. We calculate temperature increase by heat gain in the house.

Theoretically, the heat capacity which effects on room temperature variation is in direct proportion to the wall weight of inner layer of the insulation. Normally heavy material inner insulation are gypsum board or plywood in our houses. So, we scope on the layer of gypsum board. Table-2 shows calculated wall layer. Table-3 shows the thermal property used in the calculation.

Table-2: Wall specifications of the calculation

| | |
|--------|--|
| Wall | Gypsum Board 10mm + Glass Fiber insulation 16kg/m ³ 100mm |
| Roof | Gypsum board 10mm + Glass Fiber insulation 16kg/m ³ 100mm |
| Floor | Plywood 20mm + Glass Fiber insulation 16kg/m ³ 100mm |
| Window | Single glass 5mm |

Table-3: Thermal properties of material used in calculation

| | Density kg/m ³ | Specific heat J/kgK | Thermal conductivity W/mK |
|------------------------|---------------------------|---------------------|---------------------------|
| Gypsum board | 700 | 870 | 0.58 |
| Plywood | 500 | 1,880 | 0.19 |
| Glass fiber insulation | 16 | 840 | 0.04 |
| Glass | 2,200 | 900 | 12.0 |

Figure-7 shows the results of room temperature increase. Stable ratio in this figure is room temperature divided by steady state temperature. If the influence of heat capacity is small, the stable reach 100% quickly. The figure also shows result in the case of double layered gypsum board.

Both results show that the influence of the heat capacity remains long time. The stable ratio is about 95% at 10 hours later. If we use the temperature difference at that time, the estimated HLC is 5% larger than the stable result. If we switch electric heater on at 17:00 after sunset and measure the temperature difference at 5:00, the estimated HLC should have 5% larger than the fact.

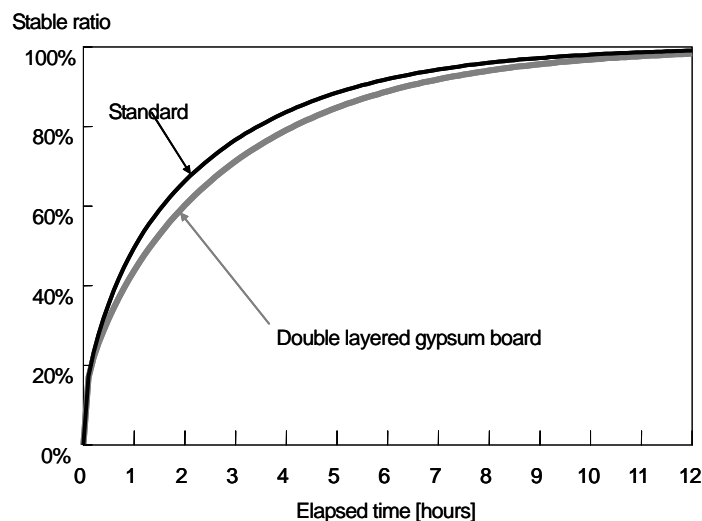


Figure-7: Calculated Temperature variation

5. Conclusions

Our trials show the measurement method gives reliable results. The necessary equipment is about 10 sets of the electric heater and temperature recorder.

There are some remaining problems which we should try to solve, such as the influence of the heat capacity of the heavier wall. Fortunately, the percent of the heavy wall, such as concrete or soil, in the all of new built houses is almost constant for last decade, a few percent in detached house.

This method is most simple and convenient to estimate the thermal performance of the house. We think this method is one of good tool for the commissioning of residential houses.

Acknowledgement

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